

A MOBILE ASTEROID SURFACE SCOUT (MASCOT) for the HAYABUSA 2 MISSION

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Introduction

MASCOT, a Mobile Asteroid Surface Scout, will support JAXA's Hayabusa 2 mission to investigate the C-type asteroid 1999 JU3 [1] that is expected to be a rubble-pile, with a size slightly larger than Itokawa. The German Aerospace Center (DLR) develops MASCOT with contributions from CNES (France) [2,3]. Main objective is to in-situ map the asteroid's geomorphology, the intimate structure, texture and composition of the regolith (dust, soil and rocks), and the thermal, mechanical, and magnetic properties of the surface in order to provide ground truth for the orbiter remote measurements, support the selection of sampling sites, and provide context information for the returned samples. MASCOT comprises a payload of four scientific instruments: camera, radiometer, magnetometer and hyperspectral microscope. C- and D-type asteroids hold clues to the origin of the solar system, the formation of planets, the origins of water and life on Earth, the protection of Earth from impacts, and resources for future human exploration. C- and D-types are dark and difficult to study from Earth, and have only been glimpsed by spacecraft. While results from recent missions (e.g., Hayabusa, NEAR [4,5,6]) have dramatically increased our understanding of asteroids, important questions remain. For example, characterizing the properties of asteroid regolith in-situ would deliver important ground truth for further understanding telescopic and orbital observations and samples of such asteroids.

Scientific Objectives

The primary objective is to provide the ground truth for the orbital measurements of the Hayabusa-2 orbiter instruments and the in-situ MASCOT sensor suite and to provide context of the undisturbed sampling sites. This is achieved by contributing to the determination of the structural, textural and compositional characteristics of the surface layer on scale lengths ranging from tens of meters to a fraction of a millimeter, by means of multi-color imaging of the asteroid's surface. Imaging will start shortly after the separation from the Hayabusa-2 mother S/C and images will be acquired until touchdown. The images will close the resolution gap between orbital and

surface imaging and allow for a location of the landing site within the orbiter camera dataset. After touchdown, the camera will acquire wide-angle images of the asteroid's surface. From these images, surface features will be mapped on scales ranging from meters down to a millimeter, allowing characterizing the surface in terms of regolith physical properties, texture, morphology, particle size distribution, and microcraters. Multispectral imaging during dark phases is achieved through an illumination device consisting of four arrays of monochromatic light emitting diodes working in 4 spectral bands. The spectral range and the spectral resolution will allow classifying and mapping the compositional heterogeneity of the asteroid's surface in order to spatially support the spectrally resolved information. The study of the spectral slope and albedo should allow for a broad classification of the solid surface phases, and to distinguish between carbonaceous, silicates and organic materials. Further, the analysis of color ratios over a given field will provide information on the degree of soil heterogeneity at very small scales. Image series at different sun angles over the course of a day will also contribute to the physical characterization of the asteroid surface properties (photometric analysis). The images may also ideally guide the selection of sampling spot(s) of the Hayabusa-2 S/C (along with other results from the MASCOT in-situ measurements). Simultaneous observation with spectrometer and the radiometer of the same surface location will provide important context information.

The descent sequence and the close-up images will reveal the surface features over a broad range of scales, allowing an assessment of the surface's diversity and close the gap between the orbital observations and those made by the in-situ measurements.

Additional imaging during the ballistic hopping - lander's relocation mode - will allow acquiring meso-scale (resolution: cm) information of the local surface and/or possible indications of horizon glow that can not be obtained by the orbiter's imaging system.

The following measurement objectives have been identified for imaging:

- investigate surface features on scales ranging from meters down to a millimeter (regolith

physical properties, texture, morphology, microcraters) through descent and close-up imaging, and photometry.

- determine the rock fragment and particle size distribution of the regolith down to scales of the order of a millimeter.
- identify compositional and textural small-scale inhomogeneities through color imaging in 4 spectral channels during dark phases.
- support the selection of the sampling area by local characterization of candidate sampling sites.
- provide in-situ geological context of the asteroid's surface as ground context for orbital measurements of Hayabusa-2 and context for all other MASCOT in-situ measurements.

MASCOT will measure the radiative flux emitted from the asteroid's surface using thermopile sensors. Six individual filters will be employed to measure the flux in the wavelength bands between 5.5-7, 8-9.5, 9.5-11.5, 13.5-15.5, 8-14, and 5-100 μm . The primary scientific goal of the radiometer is the determination of the asteroid's thermal inertia, the secondary goal is the characterization of surface mineralogy.

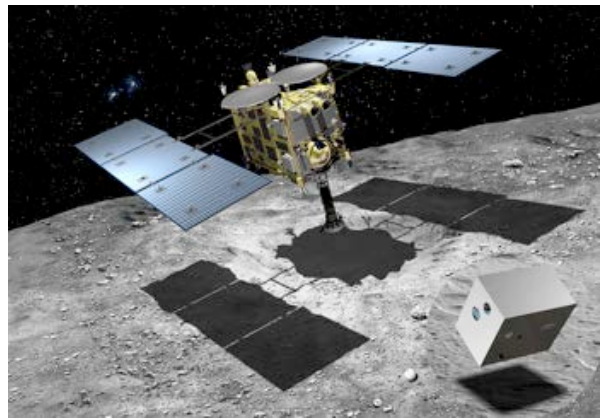
To determine surface thermal inertia, the temperature of the asteroid's surface will be measured over the period of a full rotation using wavelengths from 5 to 100 μm . The temperature sensors are capable of measuring the full temperature range expected on the asteroid's surface between 120 and 450 K. In addition, the emissivity of the surface can be estimated from the flux in the band-pass filters from 5.5 to 7, 8 to 9.5, 9.5 to 11.5, 13.5 to 15.5, and 8 to 14 μm . Thermal inertia can then be determined from an investigation of the surface radiative energy balance.

The mineralogy of the surface can be characterized from an investigation of the radiative flux in the same band-pass channels, as rock forming minerals like olivine and pyroxene have characteristic absorption features. In addition, the 8 to 14 μm filter is identical to the filter used by the thermal mapper on the Hayabusa2 spacecraft, such that measurements can be directly compared to the results obtained from the spacecraft. In this way, ground truth can be provided at small scales.

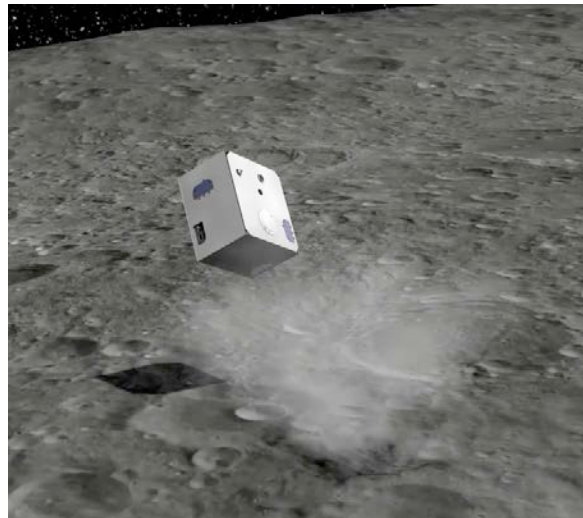
The MASCOT will measure the global magnetic field during descent and hopping phases either indicating a global magnetization of the asteroid or induction effects due to time-varying external magnetic fields. Furthermore, magnetic field vectors at the individual landing and hopping locations will be determined in order to characterize the magnetic properties of surface materials that will allow understanding the magnetic evolution of asteroidal bodies.

A hyperspectral microscope will image and

characterize asteroidal surface samples a few mm^2 in size, with a resolution of 20 μm , as to their structure and composition: on each pixel, the spectrum is acquired from 0.9 to 3.5 μm , in more than 300 contiguous spectral channels. The spectral range and resolution have been chosen so as to enable to retrieve the composition of the major and minor constituents present in each image element: most minerals, both pristine and altered, have diagnostic signatures in this domain, as well as most frosts and ices, and noticeably, organics, thus, providing a microscopic determination of the asteroidal surface composition, down to its grain scale, offering key clues to decipher its origin and evolution.



Artist's conception of HY-2 during sampling, also showing MASCOT landed on the surface. CREDIT: JAXA/Akihiro Ikeshita.



Artist's conception of MASCOT touching down and jumping across the surface. CREDIT: DLR.

Measurement scenario

MASCOT will descend and land on the asteroid and will change its position two times by hopping. This enables measurements during descent, at the landing

site, at up to two hopping positions, and during hopping. The first order scientific objectives for MASCOT is to investigate at least at one location: (1) the geological context of the surface by descent imaging and far field imaging in-situ; (2) the global magnetization by magnetic field measurements during descent and any local magnetization at the landing positions; (3) the mineralogical composition and physical properties of the surface and near-surface material including minerals, organics and detection of possible, near-surface ices; (4) the surface thermal environment by measuring the asteroids surface temperature over the entire expected temperature range for a full day-night cycle; (5) the regolith thermophysical properties by determining the surface emissivity and surface thermal inertia; (6) the local morphology and in-situ structure and texture of the regolith including the rock size distribution and small-scale particle size distribution; (7) the context of the observations performed by the instruments onboard the main spacecraft and the *in situ* measurements performed by MASCOT ('cooperative observations') and provide documentation and context of the samples and correlate the local context of the *in situ* analysis into the remotely sensed global context; (8) the body constitution on local and/or global scales and constrain surface and possibly sub-surface physical properties; (9) the context of the sample collected and returned by the main spacecraft by qualifying its generic value and processed/pristine state and thus support the laboratory analysis by indicating potential alteration during cruise, atmospheric entry and impact phases.

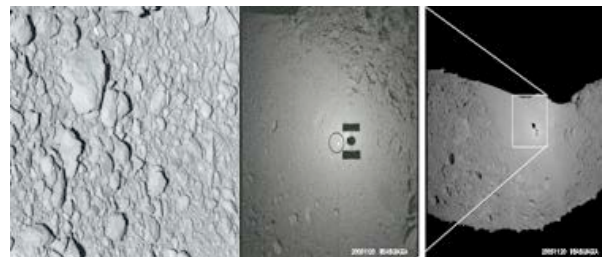
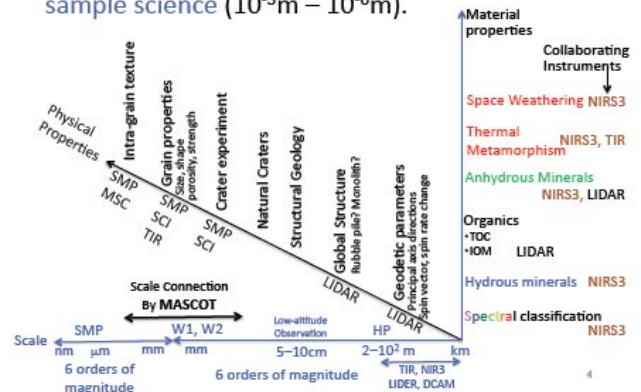
In addition to the main science objectives further science measurement can be performed by the lander's engineering sensors that are supposed to monitor the housekeeping and/or provide the right measuring orientation/position of MASCOT and by the scientific payload based on their given favorable observing conditions within the lander's nominal operation mode ('opportunity science').

Instruments

The MASCOT camera, a highly compact CMOS camera, is designed to cover a large part of the surface in front of MASCOT. It is mounted inside the lander slightly tilted, such that the center of its 55° square field-of-view is aimed at the surface at an angle of 22° with respect to the surface plane. This means that both the surface close to the lander and the horizon are in the FOV, when the lander rests on a horizontal surface. The camera is designed according to the Scheimpflug principle, which ensures that the entire scene along the camera's depth of field (150 mm to infinity) is in focus. The camera is equipped with a 1024x1024 pixel CMOS sensor sensitive in the 400-1000 nm

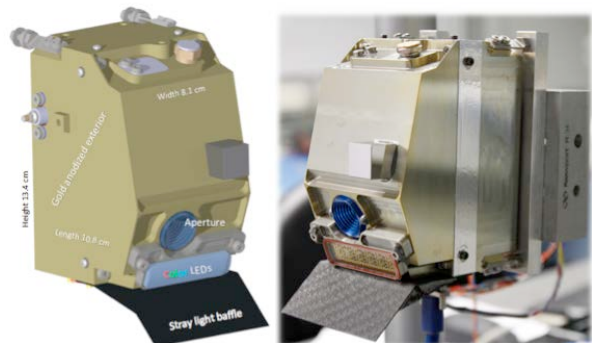
wavelength range, peaking at 600-700 nm. Together with the f-16 optics, this yields a nominal ground resolution of 150 micron/px at 150 mm distance (diffraction limited). An LED array, equipped with 4x36 LEDs of

- MASCOT will serve as a strong **tie point** between **remote sensing science** ($10^3\text{m} - 10^3\text{m}$) and **sample science** ($10^{-3}\text{m} - 10^{-6}\text{m}$).



Hayabusa 2/MASCOT combined measurement scenario.

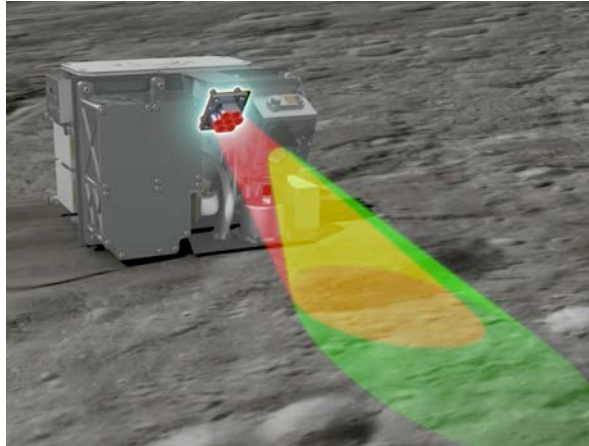
different colors (centered at B:470nm, G: 530nm, R: 624nm, IR: 805nm), is available to illuminate the surface at night for color imaging. To fit in the limited payload mass allocation for MASCOT, the camera optical head including illumination unit and electronics is designed as a highly compact camera with a low mass of 403g.



Engineering drawing and photo of the MASCOT camera flight model

The power consumption is less than 6.4W (during multiband night-time imaging).

The MASCOT radiometer MARA is a multispectral instrument, which will measure the radiative flux emitted from the asteroid's surface using thermopile sensors. Six individual filters will be employed to measure the flux in the wavelength bands between 5.5-7, 8-9.5, 9.5-11.5, 13.5-15.5, 8-14, and 5-100 μm in order to determine the asteroid's thermal inertia and to support mineralogical characterization.

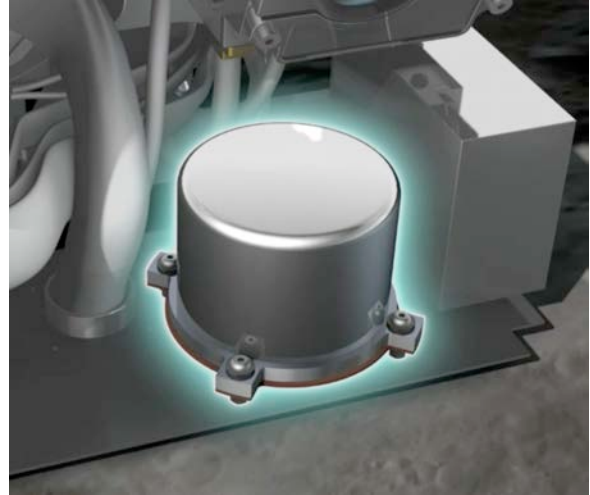


Field of view of the radiometer (red) and camera (green)

The magnetometer is a tri-axial vector compensated fluxgate magnetometer and designed to measure the global magnetic field during descent and hopping phases either indicating a global magnetization of the asteroid or induction effects due to time-varying external magnetic fields. The sensor can withstand a high range of temperatures and is moreover equipped with MLI for better temperature stability. The magnetometer has a single mode of operation for scientific purposes. After switch ON, the instrument starts to measure the magnetic field vector with 10Hz sampling rate. The instrument has low mass and low power consumption in order to fit in the system requirements for limited total mass and in order to be able to measure continually on the surface as long as possible. The enhanced emphasis will be placed on the calibration in terms of magnetic disturbances from the MASCOT system. The aim is to characterize system generated magnetic fields in order to be able to separate artificial contributions from external fields.

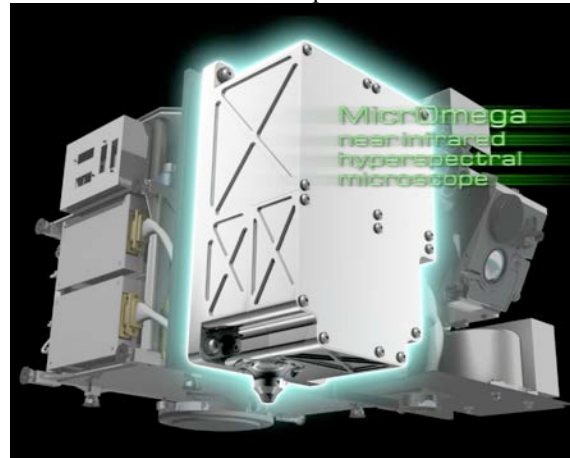
After MASCOT is positioned on the surface of the asteroid, the external window of MicrOmega is in direct contact with surface material. An illumination system, based on an AOTF (acousto-optic tunable filter), provides a monochromatic illumination of the

sample through the window, and an image is acquired on a 2D infrared detector, cooled by a dedicated



The MASCOT magnetometer is mounted on the bottom of the lander

cryocooler. Then a second wavelength is chosen, a new image is acquired, and so on: the process is repeated by sequentially tuning the illumination wavelength over the entire spectral domain, building, in a few minutes, a 3D (x,y,λ) image-cube of the sample. The hyperspectral microscope will sample an area of a few mm^2 in size, with a resolution of 20 μm , as to their structure and composition.



The MASCOT near infrared hyperspectral microscope has direct contact to the surface

On each pixel, the spectrum is acquired from 0.9 to 3.5 μm , in more than 300 contiguous spectral channels. The spectral range and resolution have been chosen so as to enable to retrieve the composition of the major and minor constituents present in each image element: most minerals, both pristine and altered, have

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References

[1] Vilas, F., Special Analysis of Hayabusa 2 Near Earth Asteroid Targets 162173 1999 JU3 and 2001 QC3, *Astronomical J.* 1101-1105, 2008; [2] Jaumann, R., J.P. Bibring, K.H. Glassmeier, M. Grott, T.-M. Ho, S. Ulamec, N. Schmitz, H.-U. Auster, J. Biele, H. Kuninaka, T. Okada, M. Yoshikawa, S. Watanabe, M. Fujimoto, T. Spohn, A. Koncz 2014: A mobile Asteroid Surface scout (MASCOT) for the Hayabusa-2, LPSC 2014 (Conference Proceedings), Lunar and Planetary Conference 45st, #1817; [3] Ulamec, S., Biele, J., Bousquet, P.-W., Gaudon, P., Geurts, K., Ho, T.-M., Krause, C., Lange, C., Willnecker, R. and Witte L., 2014. Landing on Small Bodies: From the Rosetta Lander to MASCOT and beyond; *Acta Astronautica*, Vol. 93, pp. 460-466; [4] Special Issue on Scientific results from Hayabusa Science, Vol. 312 no. 5778, 2006; [5] Special Issue on Initial Analysis about Itokawa's material retrieved by Hayabusa Science, Vol. 333 no. 6046, 2011; [6] Bell, L., Mitton, J.-., Asteroid rendezvous - NEAR Shoemaker's adventures at Eros. Cambridge Univ. Press, 2002.